Early Journal Content on JSTOR, Free to Anyone in the World

This article is one of nearly 500,000 scholarly works digitized and made freely available to everyone in the world by JSTOR.

Known as the Early Journal Content, this set of works include research articles, news, letters, and other writings published in more than 200 of the oldest leading academic journals. The works date from the mid-seventeenth to the early twentieth centuries.

We encourage people to read and share the Early Journal Content openly and to tell others that this resource exists. People may post this content online or redistribute in any way for non-commercial purposes.

Read more about Early Journal Content at http://about.jstor.org/participate-jstor/individuals/early-journal-content.

JSTOR is a digital library of academic journals, books, and primary source objects. JSTOR helps people discover, use, and build upon a wide range of content through a powerful research and teaching platform, and preserves this content for future generations. JSTOR is part of ITHAKA, a not-for-profit organization that also includes Ithaka S+R and Portico. For more information about JSTOR, please contact support@jstor.org.

ON THE

CONSTRUCTION OF FURNACES

FOR HIGH HEATS,

AND THE THEORY OF THEIR OPERATION.

By T. R. ROBINSON, F. T. C. D. M. R. I. A.

Read April 21, 1817.

WE are told that Chemistry was formerly denominated the Philosophy of fire, and caloric is still our most powerful agent; it is therefore of some importance to the practical chemist to be informed of the means by which it may be applied in the most powerful manner, and I have endeavoured in this communication to collect the facts which are scattered through the works of various authors relative to the perfection of furnaces. Little originality can be expected on such a subject, I have however attempted, where any point required elucidation, to supply what was wanting in experiment and theory; and I have given a concise sketch of the gradual improvement of these instruments down to the present day.

Of the furnaces of the ancients nothing is known, they were probably like those which the Hottentots and Mexicans used when first visited by Europeans: Chemistry had its birth among the Arabians, and we owe to them the invention of this part of chemical apparatus; in the works of Geber we find described an air-furnace exactly similar to those used at present, except that it wants a chimney. The Alchemists used the Athanor for digestions, &c. but wherever a high heat was required, they employed the Blast furnace, till Glauber added a long tube to the vent-hole of Geber's furnace. In his treatise on Philosophical furnaces, (a very curious work which contains many inventions which have of late years been rediscovered, as Woolfe's apparatus, the (a) Water-lute, the use of steam to heat a larger mass of fluid, &c.) he gives an interesting account of his contrivance. After expatiating on the vexation which the unfortunate alchemist continually suffered in his experiments with the Blast furnace, where he was exposed to poisonous fumes and the mortification of seeing his hopes disappointed by the failure of his crucibles, he tells us that he determined in a fury to resign chemistry, he sold his bellows and was disposing of the remainder of his apparatus by throwing it out of the windows, when he found in a broken crucible some grains of silver which he could not sell without fusing them into a mass. After some meditation he contrived a furnace which was so convenient that it tempted him to resume his favorite pursuit. Glauber's furnace was gradually modified by succeeding Chemists, Cramer and Boerhaave have described various forms of them, but they were not able to excite very strong heats, as the former directs Assays of Iron ore, and some of Copper to be made with the assistance of bellows opening into the ash-pit. Pott was the first who conceived the possibility of exceeding in a small compass the power of the Glass and Porcelain furnaces, and to a certain degree he succeeded, but his plan was defective as the area of his flue was only $\frac{1}{10}$ of the area of the furnace, he also entertained an erroneous idea that the draught was augmented by a horizontal tube connected with the bottom of the furnace. Macquer's furnace was very good, his attempt to explain the theory of the draught is, however, defective. He supposes that the air in the upper part of the furnace is rarified so as to form a vacuum into which the external air presses; he, however, does not explain why the air ascends rather than descends; but Baumè has supplied this deficiency by saying, that *fire,* being light, by its own nature must ascend. Macquer proceeds to state, that the current of air is more strong, as the vacuous space at the top of the furnace is the greater, and therefore it is useful to enlarge this space by the addition of a tube (tuyau d'aspiration); and to give the current velocity we must make its aperture less than that of the furnace, for fluids urged through a contracted channel must move more rapidly as the contraction is greater. (*b*)

(a) Glauber used lead, as his apparatus was red hot, and some of his experiments with it are very curious, in one, when attempting to extract a spirit from gold (for all his chemistry was occupied with the discovery of remedies,) he threw into it successive portions of aurum fulminans, and observed the production of water by its explosion.

This explanation may be a lesson to those who attempt to account for any phænomenon without the necessary knowledge; for Macquer, notwithstanding his excellence as a chemist, must have been completely ignorant of Hydrostatics, and ought to have consulted some of his mathematical friends on the subject. He, however, found that his principles were faulty; for if the tube was too much contracted, the performance of the furnace was materially affected, and he supposed this to depend on the

---

(*b*) See his Dict. de Chymie. Fourneau.

proportion between its length and diameter, as he found that if it were lengthened beyond a certain limit the draught was diminished, and that a wide chimney might be longer than a narrow one. This fact depends on the greater loss of heat in the narrow tube, the cooling surface is as its diameter, but the air to be cooled as its diameter squared, so that the latter diminishes much faster than the former. Where the tube was six inches wide, it could not be used longer than twelve feet, but much heat was lost, for it was composed of sheet iron which was heated to redness. But though his reasoning was bad, his practice was excellent, and his furnace was the best which had then been constructed. De Morveau found that it was capable of fusing Manganese and softening Platina; but it must be remarked, that at that very time a committee of the institute, who were appointed to repeat Clouet's experiments on steel, could not fuse iron in it, and found that Wedgewood's Pyrometer marked 152. Baumè's furnace was a hollow tube without any contraction, with a grate at its bottom, and he found it superior to any with which he was acquainted; but though no other chemist has adopted it, except Saussure, there is no question that it is the best form which has yet been invented. Since that time little has been done by chemists towards the improvement of these instruments: the English have acquiesced in the common mode of constructing them, and from the great superiority of coke to charcoal, their air furnaces produce, with ease, a higher heat than is necessary for most operations, so that they have not been compelled by this consideration to enquire into their defects. Whatever alterations have been made here, regard the convenience of the operator, and we do not possess any theory of ,their performance.(c)

To estimate completely the circumstances on which it depends is, in the present state of our knowledge, impossible; we are not accurately acquainted with the capacities of bodies for heat, their conducting powers are almost unknown, and we have no means of deciding whether they vary with the temperature, and according to what law. But though a rigorous investigation cannot be attained, we may arrive at limits within which the real values are contained: and as the process of combustion includes in it the consideration of fuel in a state of ignition, and of the vessel in which it is consumed, we will enquire into them separately. Combustion is well known; if a fragment of charcoal be placed in atmospheric air it suffers no change, but if it be heated to redness, it rises to a higher temperature, a portion of it disappears, while light is evolved, and the air which has supported the process, and which, when cooled, is found not to have changed in bulk, now contains no oxygen, it has been changed into carbonic acid. It is found, that the consumption of 1 part of charcoal in common air affords 9.3 parts of nitrogen by weight, and 3.6 of carbonic acid, and as this mixture cannot support combustion, it must be apparent, that the continuance of the process requires its removal and a fresh supply from the atmosphere. We are much in the dark as to many of the circumstances of combustion, I am not acquainted with any plausible reason for the necessity of a red heat to its commencement, it cannot be said that by

---

(c) In Rees's Cyclopedia, a theory of the action of chimneys is given, which is almost completely erroneous.

ignition cohesion is diminished, for charcoal becomes denser by heat, and by a priori arguments, it should even seem that as bodies burn with difficulty in rarified air, and the heat of the burning body must expand it, therefore ignition might be adverse to combustion. We are also ignorant whether charcoal burns faster at a higher temperature, and little can be affirmed about the most important products, the light and heat for which we excite it. Probably the light comes exclusively from the combustible, it is different in different bodies, and in the case of hydrogen is almost nothing, though the heat produced is intense, and the quantity of oxygen condensed enormous; the experiments of Saissy indeed would if accurate lead to a contrary conclusion, he found that by compressing in a glass syringe any gas containing oxygene (among which he reckons chlorine) which was a supporter of combustion, a flash of light was seen to pervade the barrel, but I suspect that it was occasioned by the combustion of some of the grease employed in lubricating the piston. The caloric is mostly derived from the supporter, but the combustible itself affords some, for much heat is produced by the action of certain inflammable bodies on each other, as sulphur and iron. After this brief notice we may proceed to ascertain if possible the maximum of heat which the combustion of charcoal can produce; if no caloric were lost the temperature would increase without limit, but this is not the case, some of it is dissipated by radiation, some transmitted through the walls of the furnace, and much wasted in heating the gases which have supported the combustion and are thirteen times as heavy as the fuel consumed. The influence of radiation is trifling, in fact it does not affect the interior parts of a furnace, as the coals which surround the central portions radiate back to them as much caloric as they receive, and for the same reason the conducting power of the materials of the furnace cannot much diminish the effect, the centre of the fire is surrounded by one of the worst conductors with which we are acquainted, ignited charcoal; and experience shews that in furnaces of a certain size, this reasoning may be depended on. I have produced as high a heat as ever was measured, 169 of Wedgewood in a furnace whose walls were only two inches thick, and another equally well constructed, but more massive, did not give a higher result. The loss from heating the gases is much more serious, their capacity is equal to that of charcoal, and their weight much greater, so that most of the caloric produced is absorbed by them. To ascertain the amount of the loss, let us suppose a quantity c of charcoal at the temperature θ to undergo combustion, the caloric evolved is divided between the air which has burned it and the unconsumed charcoal, now we know how much is required to raise a determinate quantity of this air θ degrees, and therefore how much goes to heat the remainder of the fuel and the crucible. It is clear that as θ is greater more of the caloric will be required to heat the gases, and of course less will remain to raise the temperature of the furnace, so that there is a certain value of it at which all would be employed in bringing them to the heat of the coals, and this would be a major limit, for if θ were greater than this, the air which had burned a quantity of fuel after receiving all the heat proceeding from it would still be less hot than the surrounding bodies, and therefore would cool them. In practice the maximum temperature is a little below this on account of the loss of heat by the walls of the furnace, as I have already stated.

Since the quantities of caloric which bodies contain are as their temperatures and capacities conjointly, the caloric procceding from the combustion of c of charcoal is represented by $C \times c \times (\theta + t)$ (where $C =$ capacity of charcoal, c its quantity, θ its temperature before combustion, and t the number of degrees of Fahrenheit which the combustion of a portion of charcoal would heat an equal portion;) and supposing all this to be found in the gases, their temperature $(= x) \times A\,a = C\,c\ (\theta + t)$, where A and a are the capacity and quantity of them, therefore $x = \frac{c\,C\ (\theta + t)}{A\,a}$: but a, as is well known, consists of 4 volumes of nitrogen and 1 of carbonic acid, or, by weight, of 9.3 nitrogen + 3.6 carbonic acid, and from this we can compute A.(*d*) As the limit is when $x = \theta$, $\theta \times A\,a = c\ C \times\ (\theta + t)$ and $\theta\ (A\,a - C\,c) = c\,C\,t$, or $\theta = \frac{c\ C\,t}{A\,a - C\,c}$ but $A = \frac{9.3\,N + 3.6.P}{9.3 + 3.6}$ and $\theta =$ $\frac{c\,C\,t}{c\left(\frac{9.3\,N + 3.6\,P}{9.3 + 3.6}\right)9.3 + 3.6 - C)}$ or $= \frac{c\,C\,t}{9.3\,N + 3.6\,P - C)}$ Now we know **$C\ t$** by experiment, **Lavoisier, Crawford** and **Dalton** have all given values of it which differ from each other considerably. I prefer Lavoisier's, which was made in the calorimeter described by him, and is, that 1 pound of charcoal gives as much heat as is equivalent to the fusion of 96 pounds of ice, 100 may be taken as

---

(*d*) Let two bodies whose capacities are N and P, be mixed in the quantities n and p, to find the mixtures, capacity A. The quantities of caloric contained in them before and after mixture are the same, as there is no chemical action, but these are as the products of their weights and capacities, therefore $N\,n + P\,p = (n + p)\,A$, and $A = \frac{N\,n + P\,p}{n + p}$, but here n the quantity of nitrogen $= (9.3)\,c$ and p that of carbonic acid $= (3.6)\,c$.

a fair statement, for the tendency of the errors in that apparatus is to diminish the result. Dalton's trial was made by a very inartificial method, and therefore is entitled to less confidence. Reckoning the caloric which is absorbed in the fusion of ice to be $= 140^\circ$ $C\,t = 14000$, N and P are known by the experiments of Laroche and Berard, (*e*) and C though with less certainty, by a mean of the numbers of Crawford and Gadolin, the first makes it .27, the other .39, .3 may be taken as a fair average, and our equation will give us $\theta = 4575^\circ$. If the fire were blown by pure oxygen as N n disappears from the denominator, it would be 6 times as great. (*f*)

Two objections may be urged against this determination, one derived from theory and one from observation, the first is that I have supposed the capacities permanent, while there is every reason to suppose that they change with the temperature. Admitting to a certain degree the truth of this, it does not affect my conclusion, for the numerator of the fraction θ is independent of the temperature, it being the quantity of caloric evolved during the combustion of an atom of charcoal: now this must be invariable, for the proportion

---

(*e*) According to these able experimenters $N = .2754$ and $P = .221$.

(*f*) If the combustible were Hydrogen, burnt with pure oxygen, the circumstances are in some degree different, the mixture is at the temperature of the atmosphere, and all the liberated caloric is found in the steam resulting from the combustion, therefore $\frac{\theta = C' \times t'}{S\,s}$, now $C't'$ is by a mean of Lavoisier and Dalton, 42000°, $s = \frac{1132}{132}$ and S by Laroche and Berard $= .85$ therefore $\theta = 5738$, or about $\frac{1}{5}$ more than the utmost heat of furnaces and much inferior to the heat of charcoal blown by oxygen. I am aware that the reverse is commonly supposed to be true, but if we consider that in the experiments which have been made with charcoal the bodies experimented on are cooled by the blast of oxygen, while in the other case, the flame is impelled on them in the most advantageous manner, and less heat is lost by radiation, we shall not be surprised at the superiority of its effects.

of oxygen which it takes is definite, and the caloric is derived from it. The denominator is affected, but the capacities of gases increasing and that of charcoal also though in a lesser degree, the whole must be increased, and therefore, the value of θ diminished, so that my result must be above the truth.

The other objection depends on the observations of Wedgewood, who supposed, that the extreme heat of a furnace was about 30,000° degrees, but we cannot place much dependance on the method which he employed; there is no evidence that his pyrometers contract uniformly, and the contrivance which he used to connect his scale with Fahrenheit's is defective; as silver is easily fusible, and bodies expand irregularly near the points at which they change their state, it is certain that the degrees measured by it are much too large. Thus sulphuric acid will scarcely boil unless the sand round the retort be red, yet it distills at 600, not far from the point where Newton determined the commencement of ignition. In the large reverberatories of the iron founderies, it is stated by Mushet, that one ton of coal fuses one ton of soft cast iron. Now it may be shewn from Watt's experiments, that, one part of coal would, *if no heat were lost,* vaporise 10 of water, therefore, to melt one part of iron, there is used as much caloric as would heat one of water, 10,000°, reckoning the latent heat of steam 1,000°. But the gases which pass through the furnace are as hot as melted iron, and are twelve times the weight of the coal, while their capacity is about .28, the caloric must therefore be divided between them and the iron. Computing on (*g*) these data we find, that the temperature at which the soft cast iron melts, is about 2,828°: now we know, that this fuses at 130° of Wedgewood, each of his degrees is, therefore 19° or 20° of Fahrenheit nearly.

Robins found, that air by a white heat, or about 35° or 40° of Wedgewood was quadrupled in volume, therefore, supposing it to expand uniformly, it must by the known expansion of air have been heated 3×480 or 1440°, which would give 1° of the pyrometer=26°. Lastly, the experiments of Beaunier and Gallois, related in the 70th Number of the Journal des Mines, give us an approximation. They exposed in a refining furnace masses of iron of known weight and capacity till they had acquired its temperature, these were rapidly withdrawn, and plunged into a quantity of cold water; the augmentation of its temperature gave the heat of the iron. They found that at the instant when the last pellicle of litharge disappears from the melted silver, its heat was 700 of Reaumur or 1575° F. and as the silver was perfectly fused though sunk deep in the hollow of the cupell beneath the current of flame, while the iron was in the hottest part, we may fairly suppose it to have been 10° W. hotter than the silver and therefore at 35° W. This gives 1° W=28° F. (*h*) I offer these estimations not as certain

---

(*g*) Let W and w be the weights of the gases and iron, C and c their capacities, and θ the temperature, then $\theta \times (WC+wc) = 10000^\circ$, therefore $\theta = \frac{10000}{WC+wc} = \frac{10000}{3.5}$ taking the capacity of iron to be .14; it is probably something greater.

(*h*) In these computations I have subducted from the numbers expressing the heats, 600° or the number of degrees before ignition commences, as Wedgewood's scale begins at that point.

but probable; I have however valued the heats in pyrometric degrees so that I think they cannot be far from the truth, and the near coincidence of conclusions derived from methods so dissimilar, is sufficient to shew that they are approximations to the real value. If we take the mean of them and reckon 180° to be the utmost power of a good blast furnace, the maximum heat would be 4320° F. not much removed from the determination of theory. Leaving this question to be decided by future experiments, we will proceed to observe that the temperature of a furnace is not uniform throughout, the heat gradually diminishes from the axis to the circumference of it, for which reason the crucible when intense action is required should not exceed a certain magnitude, and it also varies from the grate upward. When air is drawn through a body of coals, its oxygen is changed into carbonic acid gradually, and at the same time it is heated so that its temperature is continually augmenting as long as it can support combustion, afterwards it can acquire no increase. The centre of that stratum of fuel where the air is completely deoxidated I will call the focus of the furnace; and its position should be ascertained by experiment, a rod of refractory clay should be fixed vertically on the grate, and its vitrification will mark the limits in which the greatest action has taken place. In a furnace supplied with Kilkenny coal, I found that it was 2 inches above the grate, but this depends on the quantity of the fuel and also the rapidity of the current of air, as when it moves with great velocity, it will be less deoxidated in passing through a given quantity of coals. I found after an unsuccessful attempt to fuse platina, that in essaying it with a double load on the bellows, the focus rose so much above its previous place that the upper part of the crucible and its lid were destroyed while the bottom of it and the included metal were scarcely affected. Above the focus there is no combustion, but the stream of heated air communicates its caloric to the incumbent fuel, and ignites it to a considerable degree previous to its descent to a lower part of the furnace, so that it is nearly at the maximum when it begins to burn. As however the air must pass for some space in contact with an extensive surface of heated coal; the same effect must be produced in our furnace as in those experiments, where carbonic acid dissolves a proportion of its base and becomes carbonic oxide. It is the substance which burns with a blue flame over the iron furnaces, and injures the power of those of the chemist, not merely by combining with fuel of which it doubles the expenditure, but still more by absorbing much caloric during its formation. According to Dalton this gas gives out during its combustion, $\frac{5}{8}$ as much heat as charcoal, it must therefore absorb while forming about half of the intire heat. In consequence of this the upper strata of fuel are not by any means as much heated as they would otherwise be, and the gases which escape from the furnace, if its depth be considerable and the fuel free from Hydrogen, are at no high temperature. I have exposed various bodies in the flue of a good air furnace, but never found them heated above moderate redness, if the upper part of the furnace were close(*i*). We must next consider how a supply of air is directed through the fuel and maintained; the most obvious method is to apply mechanical power

---

(*i.*) De Morveau proposed a furnace which on this principle is bad, it is Macquer's with a horizontal flue joining it to the chimney, in this a muffle is placed, which he thought would be heated to a great degree by the flame, even above the heat of a glass furnace; but unless he used half burnt charcoal, he could obtain no such result.

to compress a portion of air and permit it to escape through a small aperture, and this is extensively practised by the manufacturer, and on particular occasions by the Chemist, as a much higher heat can be procured by this means than in the air furnace, but it is not necessary to examine it in detail. A more refined method consists in a permitting the gases which have passed through the furnace to escape through a vertical tube of imperfectly conducting materials: these being hot, and therefore dilated are of less specific gravity than the external air, so that the column of them which fills the tube is not in equilibrio with the external pressure, and the difference of weight between it and a similar column of air is the force of draught, the air will rush into the fireplace with the velocity due to it, and being expanded there will in its turn fill the chimney and continue the process. This ingenious contrivance was probably discovered by accident, it was perhaps invented to remove the smoke, and some attentive observer perceived that it augmented the combustion; its theory is simple although as I have already observed, we are not possessed of data sufficient to determine it completely. If the temperature were uniform throughout the tube and the specific gravity of the gases proportional to it, it would be easy to determine the effect, but as this is not the case, we must ascertain, first the law of the diminution of temperature, 2dly the weight of the column of gases, and lastly determine from them the draught. It is certain that if the tube be of uniformly conducting materials, Newton's law will be observed, according to which the quantities of heat lost are proportional to those which remain.(*k*) In this case let *h* be the distance

---

(*k*) This law is beautifully illustrated by some experiments of Biot related in the Journal des Mines; he connected one end of an iron rod with a constant source of heat, and apfrom the top of the chimney, θ the temperature there: if we consider the differentials, $d\,\theta$ is as $\theta \times dh$, for dh is as the cooling surface, and the decrement of θ depends on θ and the magnitude of that surface, then $\frac{d\,\theta}{\theta} = m.\,d\,h$, m being a coefficient depending on the conducting power of the walls of the chimney, and $l.\,(\theta) = h\,m + C$ now make $h = o$ and $C = l.\,t$, t being the temperature at the top of the tube, to be determined by experiment, the complete integral is $l\,(\frac{\theta}{t}) = m\,h.$(*l*) In respect of the S. G. of heated air, it appears from the experiments of Dalton and Lussac that all gaseous bodies expand equally and uniformly by equal additions of heat; therefore if 1 of air became $1 + e$ by one degree of Fahrenheit, it would by θ° become $1 + e\,\theta$, and its *S. G.* being in-

---

plying thermometers to different parts of its length, found that by erecting perpendiculars at those points proportional to the temperatures there, the line connecting their extremities was a logarithmic curve, it was the reverse of the case which we are at present considering, the heated body was a solid, cooled by air, here it is air cooled by a solid. He ascribes the phenomenon to the conducting power of bodies which he supposes to vary according to this law.

(*l*) The tube after some time becomes hot, and abstracts caloric from the air less rapidly than at first, but as its temperature is proportional to that of the included air, the decrements of heat must be also proportional, and the equation continues true but with a different value of m.

We may easily find what the temperature would be if it were uniform throughout the tube, for calling it x we have $x \times h = \int \theta \times d\,h = \frac{\theta}{m} + C$, but when $\theta = t$, $h = o$, therefore $C = -\frac{t}{m}$, and $x\,h = \frac{\theta - t}{m}$ or $x = \frac{\theta - t}{\frac{\theta}{t}}$. It has been asserted that knowing this we could find the *S. G.* of a uniform column of equal dimensions with that contained in the chimney, but the sum of all the $\frac{s}{1 + e\,\theta}$ is very different from $\frac{s}{1 + e\,x}$.

versely as its bulk would be $= \frac{s}{1 + e\,\theta}$, s being its S. *G.* at the temperature of the atmosphere. The differential of the column of heated air is therefore $\frac{s}{1+e\theta} \times dh$ or $\frac{s}{m} \times \frac{d\,\theta}{\theta + e\theta^2}$, the integral of which is $\frac{s}{m} \times l \left(\frac{e\theta}{e\theta+1}\right) + \text{C}$. Now when the weight of the column$=$o that is when $h=o$, $\text{C} = -\frac{s}{m} \times l \left(\frac{e\,t}{e\,t+1}\right)$therefore the weight$=\frac{s}{m} \times \left(l.\left(\frac{\theta}{t}\right) - l\left(\frac{e\theta+1}{e\,t+1}\right)\right)$ and the draught is the difference between this and the weight of an external column of the height h, therefore $= h. - \frac{s}{m} \times \left(l.\left(\frac{\theta}{t}\right). - l.\left(\frac{e\theta+1}{e\,t+1}\right).\right)$ or (substituting for $\frac{1}{m}$ its value $\frac{h}{l.\left(\frac{\theta}{t}\right)}$,) $h \times \left(\frac{(1-s.)\,l.\left(\frac{\theta}{t}\right) + s\,l\left(\frac{e\,\theta+1}{e\,t+1}\right)}{l\left(\frac{\theta}{t}\right)}\right).$ In this equation m is not found, and we must ascertain t and θ by experiment, the number obtained by introducing their values will give the space through which a body must fall to acquire the velocity with which air rushes into the furnace. This increases with h, but not as any manageable function of it, it also augments with the fraction $\frac{\theta}{t}$, but at a much slower rate, we can however deduce some important practical conclusions. In the first place, is there any maximum of draught, or in other words can a chimney be made too long? to answer this let the differential of it, or $dh - \frac{s}{m} \times \frac{d\,\theta}{\theta + e\theta^2} = o$ and by substitution and transposition, $\frac{d\,\theta}{m\,\theta} = \frac{s}{m} \times \frac{d\,\theta}{\theta + e\theta^2}$ and $1 + e\theta = s$, or, $\frac{s-\theta}{e} = \theta$. now as cannot be negative this is possible only when the contents of the tube are heavier than atmospheric air. If they have not passed through a sufficient quantity of coals to be saturated with carbon, this may be the case in the air-furnace, and when flaming fuel is burned is so in every case. Were the mixture nitrogen and carbonic acid, s would be 1.09 and θ, 45°: If on the other hand the acid is changed into oxide the chimney cannot be too long, and the draught must be augmented because $l.\left(\frac{\theta}{t}\right)$ is greater than $l.\left(\frac{r\theta+1}{rt+1}\right)$, therefore the difference of their logarithms is negative and the less its coefficient, the greater is the whole. It might however be questioned how far the absorption of caloric by the carbonic oxide in its formation might operate by diminishing θ, but as this is much more diminished than the logarithms are, there seems reason to conclude that on the whole its presence is advantageous except from the increased consumption of fuel. The upper part of the furnace must therefore be carefully closed as the admission of air there is injurious, by lessening the quantity which passes through the coals, by burning the carbonic oxide, and by lowering the temperature of the ascensional column. The force of draught is never very considerable, I observed it in a reverberatory, where of course the chimney was much hotter than it can ever be in the class(*o*) of furnaces which we are at present considering, a glass tube, like the syphon gage of an air-pump with water in its bend was luted to an aperture connected with the bottom of the chimney, the difference of the heights oscillated between $\frac{1}{8}$ and $\frac{2}{8}$ of an inch. We may therefore infer that bellows working with a load equivalent to $\frac{1}{120}$ of a pound

---

(o) From the current of flame; I have seen it so hot as to produce instant combustion in fragments of wood introduced through apertures several feet above the fire-place on the square inch deliver air with a greater velocity than can result from a chimney 40 feet high; the quantity however makes up for this. It has been said that air is much obstructed in its passage through tubes, and accordingly it has been recommended to make the inside of the tube as smooth as possible, and carefully to avoid any angles in its course. No doubt these directions are, where it is convenient, to be attended to, but the neglect of them cannot materially influence the effect. In some experiments which I made on the motion of air through tubes, and which if the duties of my station permit me, I will at some future period complete, I found that it was not much retarded by roughening the internal surface of the tube through which it passed. In one of these trials a tube of glass was used, 30 inches long and twice bent at right angles, it was $\frac{1}{4}$ inch bore, and a considerable quantity of air was forced through it from a large gasometer with a velocity of 118 feet in a second, this required 161 half seconds; the tube was then moistened with Lac Varnish, and filled with sand which coated its interior. The same quantity of air was passed through it in this state and the time was 200, but the adhering sand had diminished the width of the tube so that a correction was required (*p*), and the corrected times were as 190: 200, or in this case, the resistance was about $\frac{1}{10}$ of the entire force, this was an extreme case, for the velocity was great and the space through which it passed small, and as the retardation arises principally from the adhesion of air to the surfaces over which it passes, in a narrow tube this must be much increased.

(*p*) The correction was made by removing the sand from the interior of the tube, leaving only a narrow ring where it adhered $\frac{1}{8}$ of an inch broad. When the tube was removed entirely, the time of discharge was 156 half seconds.

Where the velocity is moderate, no diminution is observed, and the managers of gas lights find that $\frac{3}{4}$ of an inch of water afford sufficient pressure to send the coal gas through many miles of pipe, while the flames are of equal magnitude near the gasometer, or at the remote extremity. Angles do not seem to affect much the progress of air, so that it is unnecessary to raise the chimney from the top of the furnace directly. But though it is useless to be very careful in smoothing the interior of the tube, we must take another precaution, that it shall be constructed of materials which are bad conductors of caloric. Lavoisier's proposal of a double tube of iron, with the interval filled with pounded charcoal, is very good while the iron lasts, but it would be soon destroyed at high heats, particularly by the sulphurous fuel of this country. On the large scale a similar contrivance is used with success, and has the additional advantage of preventing the ruin of the structure. In the immense fires of large steam engines, distilleries, &c. the interior of the tube is in a state of strong ignition through its whole extent, and if the tier of bricks, in immediate contact with the flame, be firmly connected with the remainder of the fabric, the whole must be disjointed and shaken by their unequal expansion: but when it is constructed with a double wall, separated by an interval of some inches, the interior one is seen to rise, when heated, above the other, and as it cools, gradually to subside. For the chemist, a nine inch wall will generally be sufficient, and if he fears its expansion, a few iron hoops will give it the necessary strength.

We have already seen, that the draught increases with the height of the chimney, but have not considered the influence of its diameter, as it does not directly affect the velocity of the current; but it is not to be neglected, for as we have already stated, a column of air of large diameter, will be less cool'd than a small one, and in addition to this, as the current moves through the fuel with a determinate velocity, the wider the chimney is, it will move the slower there, and experience less friction. But still more necessary is it to have it of large dimension, on account of the dilatations which the air must experience in passing through the fire-place, for it is obvious, that a free passage should be afforded to all the air which can enter between the fragments of fuel. Now the air in the flue or narrowest part of the funnel may be heated 1000°, and this temperature will triple its volume, the area of the flue therefore should be three times that of the apertures in the fuel at least. The magnitude of these depends on the quantity of space occupied by the fuel, compared with the vacuities between them, and I endeavoured to ascertain the proportion by the following method: A vessel, whose capacity was known by weighing the quantity of fine sand which filled it, was filled with fragments of coal, of such a size as I found produced the best effect in my furnace (about the size of a walnut); sand was then poured in till all the interstices were filled up, and the ratio of this to the entire content of the vessel was the ratio of the whole space to that which was unoccupied by coal. In three sets of experiments made with vessels of different shapes and sizes, I found that the numbers differed much less than I expected, and the mean gave 219 to 100, therefore the solid content of the furnace is to the bulk of the fuel as 219 : 119. These magnitudes however have 3 dimensions, while those which we wish to compare, namely the horizontal section of the furnace and the portion of it occupied by fuel have only two, and therefore are as the squares of the cube roots of the above numbers, that is as 1,502 : 1, or nearly as *3 : 2*, the apertures in the horizontal section are then about one third of the area of the furnace. It appears from what has been previously stated that the chimney should be thrice as great or equal to the total area ; and this gives the construction which is recommended by Baume and Saussure, a vertical tube of uniform diameter with a grate at the bottom. The intervals between the bars of the grate must be greater than $\frac{1}{3}$ of the area, because they are partly obstructed by the coals, but as the fragments of fuel are in this case in contact with flat surfaces, about $\frac{2}{3}$*ds* of the intervals are pervious ; on this supposition the breadth of the bars should be equal to the intervals, and no evil can arise from making them narrower. Furnaces are in general very badly constructed in both these respects, the grate is often made of square bars whose thickness is three times their interval, and it seems to have been feared that the heat might escape up the chimney, to judge from the smallness of its aperture. Pott allowed a flue of 4 inches for a fireplace of 18, and Boerhaave one of 3 to a fireplace of 12, even now we sometimes see them in the proportion of one to four, but we may be certain that all such perform badly. We are not sufficiently acquainted with pneumatics to pronounce on Venturi's chimney, which depends on the fact that a diverging ajutage increases the discharge of water from an orifice ; if the same is true of air, the tube should be a frustum of a cone with the wide end upward, and De

Morveau asserts that one of this form performed as well as a cylinder of twice the length. A more certain method of increasing the draught where the height of the chimney is limited might be the application of a small furnace to heat the interior of the chimney by its flame, it should open into it immediately above the flue and be constructed like the fire place of a reverberatory. On the furnace itself little is to be said, it should be cylindrical, formed of a double row of fire bricks moulded according to its figure and arranged in a case of strong sheet iron; these, from the species of arch which they form, possess great strength and are not loosened by the alternate expansion and contraction to which they are liable, such an instrument has been in my possession for some years and is still uninjured, it was not however constructed on proper principles as to its flue and I have ceased to use it, its bricks were to prevent *pyrometric* contraction, (or that which Wedgewood observed in clay when heated) baked in a violent heat, and no subsequent shrinkage has taken place. The parabolic and elliptic shapes which the old chemists extolled so highly are useless, the reflection and radiation of caloric take place only in transparent media, and the crucible which occupies the centre of a furnace is effectually screened by the surrounding charcoal from any influence of its walls, and the only direction which remains is, that its depth from the bottom of the flue to the grate should be at least twice its diameter. If these principles be observed, the chemist will be satisfied with their result: in a furnace whose area was 99 inches and its chimney narrower than it should have been, I have obtained intense heats, on one occasion I obtained a button of manganese which weighed 115 grains, after 2 hours and a half, and I imagine few instances occur where a higher temperature is required. I should now conclude this disquisition which has already exceeded its proper limits, yet I am induced to trespass still more on the indulgence of the Academy and give a succinct account of another species of furnaces, which is as important to the manufacturer as the air furnace is to the chemist; I mean that which acts by the combustion of coal gas, being in fact but a blow-pipe on a large scale, and to which the French in their zeal for appropriation have given the name of fumivore. They are of indispensable use where large quantities of materials are to be heated, and their improvement is beneficial, not merely to the manufacturer who employs them, but to all in their vicinity. What a gloomy spectacle does one of our large towns present to a foreigner, it is covered with a murky shroud of smoke, its edifices are blackened and disfigured, while the very lungs of its inhabitants are stained by the sooty atmosphere which they inhale! Even a common observer, when he sees a pitchy cloud disgorged from the chimney of a steam engine floating on the wind to an immense distance, views it with disgust as a foul blot in the landscape, and he from whose establishment it proceeds would feel equal annoyance at the sight of it, did he know that in it the most valuable part of his fuel is uselessly evaporated: yet this is actually the case and it is not an exaggeration to say that one third of it is thus lost. Attempts have been made to remedy this nuisance, but have not hitherto been completely successful, at least we may conclude so from the fact that the contrivances which have been proposed are not adopted; I will therefore give an account of them, and endeavour to ascertain the causes of their failure, previously stating the circumstances of the combustion of pitcoal which differs materially from that of coke or charcoal. When a furnace is charged with this fuel, it must be apparent that the temperature is much inferior to that which would be produced, if the combustible were free from gaseous and vaporisable matter, these in assuming the elastic state absorb an immense quantity of caloric which is in general completely lost; besides the coal fuses and agglutinates so that the afflux of air is not as free as in the former case, and the upper strata of fuel cannot burn from the want of oxygen. We may therefore consider them as exposed to distillation, so that the tar, gas, &c. which proceed from them make their escape through the chimney unaltered: and may conclude that in general coal does not produce more heat than it would have done if previously coked or reduced to $\frac{2}{3}$ds of its weight; it cannot even afford so much. But the volatile products are highly combustible, there is no reason why they should not burn if oxygen be present, and if a stream of air be mixed with the smoke and the mixture ignited, experience shews that it is totally consumed. The first trial was made by Mr. Watt, it was not much different from the stove of Dalesme which is mentioned in one of the first volumes of the Philosophical Transactions, and may be described in a few words as an inverted furnace, the chimney proceeds from the ash-pit and the draught is downwards through the fuel. Let us suppose the fireplace to be nearly filled with ignited coke and that a quantity of raw coal is laid on the top, from the impression of the heat it will be in part volatilised, and the smoke must be drawn through the fuel along with the air which maintains the combustion, it will therefore be consumed and the resulting flame may be directed on the body to be heated. He found that the apertures between the coals could not admit enough of air to burn the smoke completely, and he introduced an additional portion immediately below the grate. I am not acquainted with the practical value of this invention, in fact I know it only from Watt's paper in the Repertory, and a drawing of one attached to a Scotch still in the 6th volume of Tilloch's Magazine; I have however mentioned it as it seems to be forgotten, it will probably be valuable in small stoves, but in large furnaces the slag would I think soon choak the grate and we cannot remove it without interrupting the draught by opening the ash-pit. Mr. Roberton of Glasgow attempted to produce the same effect by a much simpler contrivance. He feeds the fire through a door which is constantly filled with coal, and thus no large aperture is left through which a stream of cold air may rush to lower the temperature, the fuel which is introduced gives off its elastic products which are mixed with air, admitted through a slit over the door, and are burned in passing over the coke which occupies the posterior part of the furnace; as soon as flame ceases to be formed, fresh coal must be introduced which pushes forward the former portion now completely coked: and with attention to supply it in small quantities and at short intervals of time, not an atom of smoke will escape from the chimney, at least in the reverberatory furnace: the apparatus does not succeed so well, when applied to heat a boiler. It will readily appear that the mixture of air and coal gas cannot be much heated while it is in contact with a metallic surface whose temperature is not far above 212, it must therefore escape unconsumed into the chimney where its combustion may be expected to take place, but this contributes nothing to economy of fuel, it rather produces an opposite effect, as the air admitted through the slit will unquestionably be heated at the expence of the boiler.

This will demand more fuel than would have been necessary if the furnace were perfectly closed, and the encreased expenditure is probably the reason why fumivores are not universally used ; but surely the improvement of these contrivances is an object of national importance ; and as I have pointed out the probable cause of disappointment in Mr. Roberton's apparatus, it is to be hoped that manufacturers will turn their attention to the subject. I had in conjunction with Mr. Kiernan tried many experiments to this effect even before I knew that any thing had been done by others, and we observed this defect of which I have spoken, the remedy was obvious and on trial it succeeded, the smoke must not be permitted to come into contact with the boiler until it is enflamed, and therefore the fire-place must be detached, and we must resign the caloric which is radiated from the fire, employing only the current of flame. Our experiments were necessarily made on a small scale, they however were completely successful; and the destruction of the smoke was attended with a great increase of heat. In a reverberatory whose bad performance had excited us to these experiments, this was remarkable, it had failed to fuse brass in its original condition, and with (*r*) nearly the same quantity of coal it became capable of fusing cast iron and vitrifying Stourbridge clay. A sand-bath, of which I annex a plan to explain in what our method consists, had a grate 9 inches square, the flame was directed round two sandpots 18 inches

(*r*) More coal was burned on account of the increased draught.

in diameter, and, though the fire was so small, the sand could be easily made red hot in that nearest to the fire, sulphuric acid distilled freely, and, in calcining magnesia, the bottom of the retort was melted. Mr. Kiernan altered according to our views a furnace which heated a steamboiler of the capacity of 50 gallons, its area had been 15 inches,it did not *raise the steam* in less than two hours, and was a nuisance to the vicinity. The fire-place of the fumivore was 10 by 16, much too large as we discovered, and it made the water boil violently in 25 minutes. We endeavoured to ascertain what the effect was more accurately, a fumivore had been adapted to a still in the laboratory of the Apothecaries-Hall, with a fire-place of 9 by 16, we charged the still with 125 gallons of water and kindled the fire, having weighed a quantity of coal for the experiment; in an hour and five minutes the water began to distill, and the process was continued for 5 hours more, in which time 67 pounds of coal were burned and 70 gallons of water (*s*) distilled, which gives 8. 87 pounds of water vaporised by every pound of coal, something above Watts's maximum, although the form of the still was not the most advantageous, its bottom being concave so that the flame did not touch the central part of it. We have tried many other experiments with equal success, but it would be useless to detail them as they are similar in their results to those already stated, and we have not yet had an opportunity of making any on a very large scale. It is (*t*) however necessary to observe that the performance of these

---

(*s*) During the first hour 45 pounds of coal were introduced into the furnace, so that it was full when the distillation commenced, and I reckon that 67 were consumed afterward, as that quantity was supplied, and the fire-place was full when the experiment was ended.

(*t*) If a large quantity of coals be introduced at once, the furnace ceases to consume its smoke, on account of the reduction of the temperature, but this continues only for a few semachines depends greatly on the attention of the fireman ; the supply of fuel should be nearly uniform, but if the attendant, as is usual, waits till the furnace is nearly empty, and then throws in a large quantity of coal, we may indeed burn the smoke by opening the register so as to admit more air, but it is not possible to do this without losing much heat and such alternations should be avoided ; if a steam engine were at hand it would perhaps be advisable to feed the fire by machinery, and leave to the workmen only the care of keeping the grate open, as it is liable to be choaked with slag.

I will now conclude this long discussion, with the hope that some person may resume the subject whose situation can enable him to prosecute these experiments, and give them that publicity which is necessary to make them useful ; if it be found that the fumivore is as effective when applied to a large furnace as we found it, the use of it should be enforced, and not left to the mere option of the manufacturer. It is not a diminution of the liberty of the people to say that no establishment shall be tolerated which incommodes its neighbours, at least when the inconvenience can be prevented. Interest is not always adequate to overcome prejudices, but it is not to be expected that they should be gratified at the expense of the health and comfort of thousands. We hear every day some proof of the necessity of legislative interference on this head ; in fact where a manufacturer does not avail himself of the resources which the wide diffusion of knowledge places within his reach, he is to a certain degree criminal, but he is doubly so where his neglect endangers others.

---

conds : the fact confirms my opinion of the defect of Roberton's apparatus, and I have observed another to the same effect ; all our fumivores smoke when the fire is kindling and, until the roof of the fire-place is red hot.

For instance, a high pressure steam engine should be presented as a nuisance of the most formidable kind, and its employment among a croud of workmen on no account endured. The artist whose trade diffuses nauseous exhalations (as the chandler) should be compelled to direct them through the fire of his boiler, and in fine no annoyances should be tolerated but those which admit no remedy, and which are I trust few in number; the power of man is, as Bacon observes, commensurate with his knowledge, and it therefore is capable of effects surpassing all calculation.

T. R. ROBINSON.

April 15, 1817.

EXPLANATION OF THE PLATE.

Fig. 1, is a vertical section of the sand-bath, on a scale of $\frac{1}{10}$. Fig. 2, a horizontal section; the letters of reference are the same in both: A is **Mr. Roberton's** door, a species of tube which is constantly kept full of coals; at the upper part of it is seen the slit through which air is admitted.

B is the fire-place; the flame proceeds through the flue C into the cavity D, which corresponds to the shape of the sand-pot, leaving round it a vacancy of three inches; here it is constrained to descend and surround the bottom of the pot by the stops E E, of baked clay, which are fitted to the sides of the pot.

The second flue *C*, conducts it to a second cavity *D*, arranged as the first; and it finally escapes through F into a vertical tube fourteen feet high.

The draught and heat are accurately governed by a semi-circular register in the door of the ash pit, and a sliding door in the chimney, which do not require a particular description.

Fig. 1.

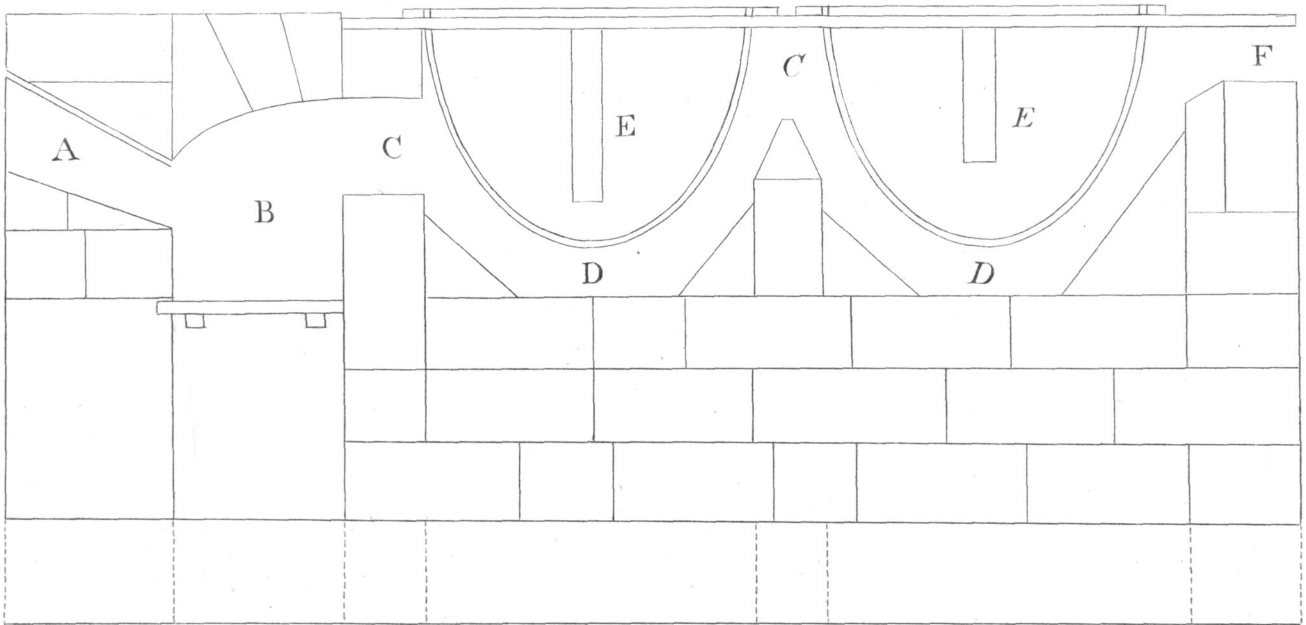

Fig. 2.